WAVEFORM ANALYSIS TECHNIQUES OF JOVIAN S–BURST OBSERVATIONS

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Abstract

As Jovian S–bursts are planetary non–thermal radio emissions with a very intrinsic substructure characteristic, it is necessary to focus on the waveform of these signals. Common techniques suffer on the one hand from the methodology itself (e.g. Fourier) and on the other hand cannot achieve sufficient time–frequency resolution. The wave initiated by the emission phenomenon, the cyclotron maser instability, gets modified through its propagation till the antenna and then further on through the receiver chain. All these effects have been carefully taken into consideration. The waveform receiving system WFR is a fully digital broad–band kind of transient recorder. It operates at the borders of at present technology possibilities. Observation campaigns with this device have been carried out at Nançay (France) and Kharkov (Ukraine). The obtained data are unique since it is possible for the first time to work on broad–band waveforms of received S–bursts. Various data analysis techniques, as for example Wavelet transform, visualize the possibilities as well as the problems obtained by this procedure. Finally possible future projects like the usage of the WFR for broad–band VLBI or for space applications are discussed. At present an unsurpassed high resolution analysis was done by Carr et al. [1997]. The waveform attempt of Carr et al. is a very promising one. By building a fully digital waveform receiving system, capable of exploring a broad frequency range many instrumental limitations and error sources can be eliminated.

1 Introduction

The Jovian radio spectrum is ranging from below 10 kHz to above 3 GHz. The wavelengths start from kilometric, hectometric through decametric till the decimetric range. The emissions characteristics and the emissions mechanisms are quite different within these ranges. The mechanism of decametric burst radiation is a collective interaction between emitting electrons gyrating around a magnetic field line. The attribute "burst" itself already describes the behaviour and occurrence of the emission phenomena: They

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sporadically occur in the time–frequency plane. Jovian S–bursts might be a kind of "prototype" for planetary radio bursts. They are the most powerful radio emissions in our Solar system: With a flux density up to $10^{-16} W m^{-2} Hz^{-1}$ at 1 AU distance they are more powerful than intensive type III Solar bursts. Exploring the substructure of Jovian S–bursts seems to be an important way to understand these phenomena. High frequency–time observations have been performed by using large radiotelescopes like UTR–2 (Kharkov, Ukraine), Nançay decameter array or the Florida antenna system in combination with high resolution receiving systems.

2 Waveform receiver

For planetary radio emissions, which are throughout incoherent and highly fluctuation structures, the Fourier transformation is not the optimum approach. The better way is to receive and store the original waveform. This is the simple but very powerful concept of the waveform receiver.

The central technical parameters are summarized below:

- **dynamic range**: 70 dB
- **bandwidth**: 25 MHz (for single channel mode) and 12.5 MHz (for dual channel mode)
- **number of channels**: 2
- **maximum length of the signal**: 30 times 6 seconds continuous recording

The digitized data is transferred via the PCI–bus to the internal memory of a standard personal computer system. The amount of memory immediately defines the maximum length of the signal. For the first prototype 640 megabyte of internal memory where used, producing data files that exactly fit on one CD–ROM.

After the acquisition the observer needs to check the data for interesting phenomena and then to decide whether the data are useful or not [Leitner, 1999, 2001].

3 Observations

The waveform was used as part of the INTAS program "New Frontiers in Decameter Radio Astronomy" [Rucker et al., 2001b], which in general explores the abilities of decameter radioastronomy and which itself is a feasibility study of a new giant decameter radiotelescope. Within this program the receiver was used during Winter 2000 at the world largest radio telescope in the decametric frequency range UTR–2 (Ukraine). The second observation campaign was done at Nançay (France), with the possibility to observe at full polarization mode with two channels.

Figure 1 shows one example of a dynamic spectrum, which is analyzed in detail in the next section.

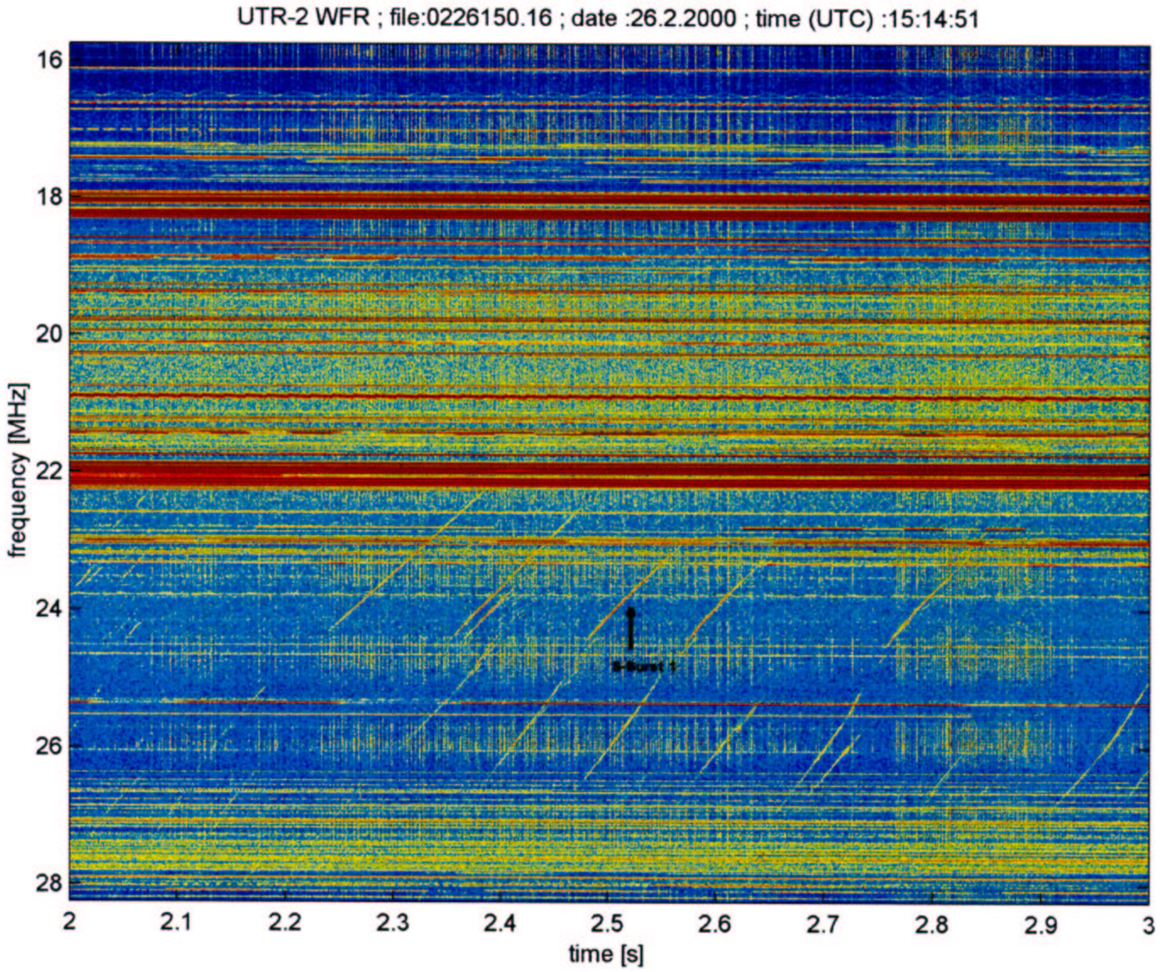

Figure 1: UTR–2 observation of an Io–C emission from February 26, 2000. Intensive "ideal" S–bursts are appearing arround 24 MHz. Due to a bad preamplifier setting the WFR was saturated.

4 Analysis and conclusions

The first attempt to look inside the burst substructure is Fourier analysis. In this case a compromise between time and frequency resolution has to be found, since the *uncertainty relation*, which states that the concurrent localization of a signal in time and frequency is impossible, cannot be broken.

A dynamic spectrum produced by this technique with very high frequency resolution is shown at the bottom panel of Figure 2.

Trying to further zoom inside the burst stops at the Fourier techniques and turns to waveform analysis techniques as the Wavelet transform.

Wavelet transformation is commonly used for the analysis of very "local" behaviour of signals or time series [see Chui et al., 1997]. Fourier's sine basis function is much to far extended in time, so that local phenomena are averaged out. An ideal mother–wavelet for that sort of signals is the Morlet Wavelet.

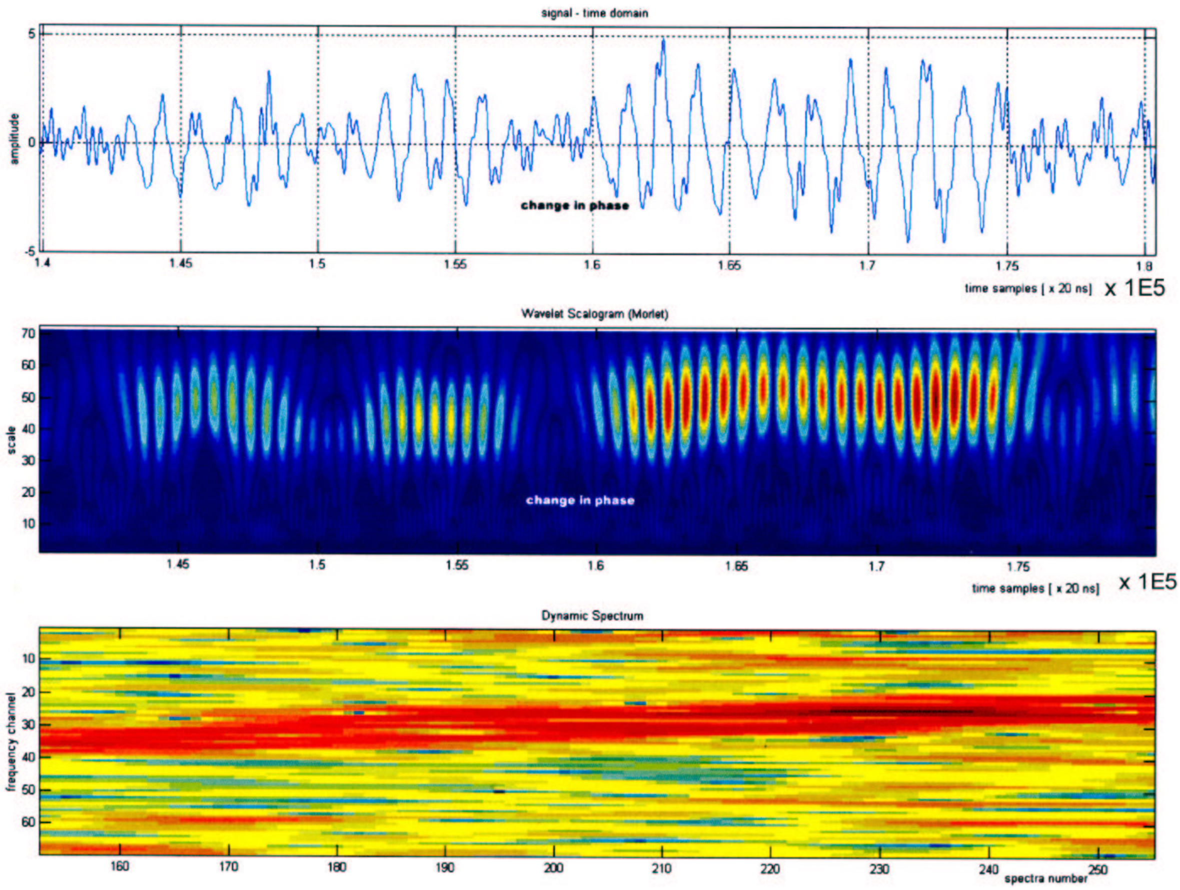

Figure 2: Time, scale and frequency domain of an S–burst time series. The upper panel shows the time series of the burst for a duration of 0.8 ms. The middle panel shows the Wavelet scalogram (Morlet) and the bottom panel displays the dynamic spectrum.

Interferences cannot very well be distinguished from the S–burst signal in the scalogram. Therefore the signal has to be filtered to attenuate all frequency bands except the S–burst bandwidth. Before starting to analyze this signal with Wavelet transformation a further frequency translation is done. The reason for this further downmixing of the burst to a lower frequency is a noise reduction in the scalogram.

The Wavelet scalogram offers a new picture of the signal. The noise is nearly completely removed and the signal level reaches very low intensities between the high intense signal bunches. The first two last about 100 μs and the third one lasts about 300 μs. Traveling at the speed of light the distance of the wave train is between 30 to 90 km long, which also should approximately correspond to the size of the source region. A further interesting fact is a change in phase of about 180 degrees between the two short and the long signal train. The signal bunches themselves are coherent in phase. Converting this fact to a physical model could mean a coupling between distinct emission subregions or a movement of an electron bunch through regions with good and bad CMI generation conditions.

5 Future aspects

Waveform analysis as additional tool to spectral analysis surely will be one of the key techniques to successfully explore intrinsic signal structures. A multipurpose receiver, capable of various techniques, will be the "state–of–the–art" inventory of a radio astronomy laboratory.

Further VLBI observations with several broad–band waveform receivers, will allow broad–band VLBI observations. This will be the first VLBI S–burst observations at all. For space missions optimum signal transformation and thus compression algorithms have to be used, designed to explore certain signal features.

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